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PRODUCTION, CONTROL AND UTILIZATION OF EXTREMELY HIGH DENSITY RELATIVISTIC STREAMS

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A tapered form of diode has been used successfully to provide for delivery of the beam with reduced distance to the wall and resultant more effective delivery of material from the wall into the beam channel to aid in formation of the super-pinched beam. Machine impedance characteristics need to be cleaned up in order to complete the investigation of the operation of the tapered tube.

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ABSTRACT

A tapered form of diode has been used successfully to provide for delivery of the beam with reduced distance to the wall and resultant more effective delivery of material from the wall into the beam channel to aid in formation of the super-pinched beam. Machine impedance characteristics need to be cleaned up in order to complete the investigation of the operation of the tapered tube.

Objectives

The objective in this work is to produce intensely concentrated relativistic electron beams by projecting more than fifty thousand amperes at more than four million volts in more than thirty nanosecond pulses in beams less than one millimeter in diameter and with mean angular divergence less than five degrees, into plasmas capable of anti-pinching residual electrons out of the channel and enabling the relativistic beam to super pinch itself to diameters of tenths of a millimeter, which when projected into appropriate solid state targets will produce nuclear and radiation flux densities similar to those in nuclear weapons and when projected into other solid state targets can meet other urgent requirements of the Air Force and also certain other very essential needs in the national interest.

Now that methods have been found for delivering the relativistic electron beam in vacuum towards the anode within a mean radius less than three millimeters and a mean angular divergence of less than five degrees, experiments have been undertaken to examine the processes produced in front of the anode by the interaction of the relativistic beam with the dense plasma produced in front of the anode by the impact of that beam on that anode. It will be of particular interest to determine which designs and materials are most effective for promptly (within less than one nanosecond) producing high density plasma immediately in front of the target position on the anode so that the initially rising relativistic electron beam current will anti-pinch the residual plasma electrons out of the beam channel thereby enabling the plasma ions in the electron beam channel to super-pinch the relativistic beams to a mean radius of 0.1 millimeter.

Earlier experiments showed that when the target consisted of a metal rod or thin-walled three millimeter tubing filled with polyethylene and extending out from the anode plane, the high energy electron beam converged on the rod or tubing, ablating metal from the outside and producing an inwardly converging cylindrical shock front which raised material along the axis to such a high temperature as to explode the rod or tubing and blast away all material before it.

When the plastic filled steel tubing, grounded to the anode plate and extending out from it, is surrounded with a graphite shroud more than fifteen

millimeters in diameter, the first seven millimeters of the filled tubing explodes and blasts away the surrounding first seven millimeters of shroud, showing that the portion of the high energy electron beam falling outside of the end of the tubing while moving through the first seven millimeters of the graphite converges on the tubing, ablates material from the tubing which shatters the graphite outwardly from the axis at the same time that the centrally inward shock injected in the polyethylene bursts the polyethylene and the remaining steel tubing over the length of about seven millimeters.

In some more recent experiments, we have successfully projected the beam out of the diode through a 0.05 mm titanium foil into room air at atmospheric pressure, and while holding the beam to the same or smaller radius, delivered the beam into metal targets 50 mm away and blasted holes through the targets. This was done by providing for the return current with six 1.5 mm aluminum rods arranged as a 10 mm diameter squirrel cage with a 3 mm thick aluminum disk as target at 50 mm from the foil. While electrons at this energy (order of 4 MeV) in air at atmospheric pressure produce ionizations at a rate of the order of one per pico-second, this alone is not sufficient to neutralize the space charge of the beam and prevent blow-up. Enough electrons produced by ionization must also be removed from the beam channel for this prupose. Initially, the increasing current in the first part of the pulse of relativistic electrons in the beam induces electric fields in and around the beam channel that accelerate the electrons liberated in the ionizations ("residual" electrons) that move those electrons in the opposite direction from that of the beam electrons and the interaction of this motion with the magnetic field of the beam is magnetically to anti-pinch the residuals out of the beam channel. The radially outward magnetic force acting on the residuals is then enhanced by the electric field of the negatively charged beam electrons. Further pinching of the beam in the course of its travel towards the target after emergence through the titanium foil has been seen in some photographs taken with a telephoto lens at three meters from the target assembly, where the X-ray intensity is down enough to avoid excessive fogging of the film.

When the titanium foil was covered with a graphite shroud having a 3 mm hole in it and tapering in thickness from 3 mm at the hole to 12 mm at 16 mm from the axis, some of the beam falling on the shroud outside of the central

3 mm diameter hole was able to penetrate the shroud and foil outside of the hole. When a 1 mm thick wafer of polyethylene was placed in the 3 mm hole in the shroud, the beam was better focused in the diode and more of the beam pulse reached the aluminum target disk and exploded a hole through that disk.

These and some similar experiments have shown that in order to concentrate the beam there will be needed both a source of dense (almost solid state density) plasma near the anode, and also a source of positive ions in the beam channel along the entire distance from cathode to anode in the diode to hold the beam together until it encounters the much denser source of ions near the anode. Experiments are continuing to accomplish these objectives.

Measurements are being made: (1) of total neutron yields both forward and laterally, using silver activation detectors; and (2) of time of flight of neutrons both forward and laterally, using scintilator detectors with photomultipliers. The latter measurements are used for distinguishing fusion neutrons from the others. By gating out the effects of the X-ray burst, the sensitivity of the latter will be increased 2 to 3 orders of magnitude. Improvements are also being made in threshold activation measurements.

In this kind of work it is desirable to have a source of supply of deuterated polyethylene, but the only source of this material has been some that was synthesized at Livermore several years ago. This has been largely used up and the little that is left is being kept for use at that Laboratory. That was not the best material that could be made because the molecular structure was not in the form of long chains but has many cross-linkages. It is possible to set up production of a higher grade of pure deuterated polyethylene free of cross-linking here at this University.

The primary objective in this program has been and is to develop methods for concentrating electron beams of more than fifty thousand amperes with energies of more than four million electron volts in thirty nanosecond pulses into beams with radii of less than three millimeters, and to develop methods for further concentrating those beams into radii of the order of one-tenth millimeter thereby producing power densities sufficient to produce nuclear and radiation flux densities similar to those in nuclear weapons. The concentrating of the beam to within a few degrees of divergence and a few millimeters radius has already been accomplished in the course of this program by the development of the

dielectric cathode over which the guide pinch forms and delivers the concentrated beam. Some concentration of the beam has also been accomplished by using a pointed metal cathode in combination with a dielectric annular ring consisting of a disc with a hole in it approximately forty millimeters in diameter aligned on axis with the cathode and with the front face of the annular ring flush with the tip of the cathode.

Purposes

The accomplishment of the above objective will lead to a very diverse range of areas of application, some of which may be indicated as follows.

By projecting the beam into a solid state target, a very dense plasma (order of 10^{23} ionized atoms per cubic centimeter) at a temperature of the order of 10,000,000 to 100,000,000 degrees can be produced, the radiation from which is in the X-ray range. In order for the effects of such X-rays to be observable most readily, it is desirable to bring the concentrated electron beam out of the vacuum space where it is produced, and to make the beam strike the solid state target in an atmosphere of chosen composition and density into order to facilitate the utilization and observation of the effects of the radiation. The energy contained in the above mentioned pulse would be in the order of forty kilojoules of which it is expected that ten kilojoules should be delivered as radiation. As soon as this objective has been achieved, the X-ray intensity is to be greatly increased by using an appropriate deuterium-rich target and driving some fusion-like reactions.

The projection of the beam through a thin foil or in any other manner so as to produce and retain the order of 10^{10} ions in an ion cluster in the beam smaller than the beam diameter will result in the coherent acceleration of the ion cluster up to the velocity of the electrons. For example, if the cluster consists of lead or uranium ions, the acceleration of these ions to the velocity of the beam gives each ion an energy of the order of 4×10^{12} electron-volts which is much larger than the ion energies produced in the most powerful accelerators in existence today. The energy of the entire cluster is of the order of 6 kilojoules. These are ion energies in the cosmic ray range of energies, and the impact of such an ion cluster upon a solid-state target of medium or high atomic number material would produce an explosion of a kind never before experienced on earth. The military consequences of such a development are difficult adequately to comprehend at this time but it should be obvious that they will be of such importance that it would be disastrous for this Nation to fail to be the first to succeed in this effort.

There have already been some interesting spin-offs from the development of the dielectric cathode which was accomplished in this Laboratory recently. That cathode delivers a relativistic electron beam in a much better collimated

form than do other cathodes, and the projection of that electron beam upon appropriately shaped metal anodes has produced intense pulsed ablation from the target area, thereby injecting very steep shocks into the metal anodes. When the target area is convex, the injected shock converges and at the focal position produces temperatures which are so high as to explode the target. This is a quite new application of the principle of the shaped charge and could be refined to produce much more intense local shock conditions. We are not pursuing the investigation of these shock effects at this Laboratory.

Another spin-off has arisen while the Chief Investigator was acting as a Consultant to the Los Alamos Scientific Laboratory. The remarkable properties of the dielectric cathode, which have been confirmed experimentally, can be applied in using these cathodes for directly injecting energy into gas lasers at high pressures without the need for windows or any vacuum spaces at all. If experimental tests prove these predictions to be correct, it will be possible to produce lasers at several orders of magnitude greater power output than any available today. This work is proceeding at Los Alamos and not at this Laboratory.

Concentration of Beam

The thesis upon which this program is based is that by providing a sufficient positive ion density in the beam channel to neutralize the relativistic electron beam space charge, the beam will be concentrated by the resulting intensified pinch effect (called the "super-pinch") to smaller diameter and deliver several orders of magnitude greater power density than ever before achieved. In order to accomplish this, there are several interacting processes which must be put into a proper relationship and maintained there as follows.

In the high voltage diode, during the time the applied voltage and resulting current are both increasing, the electron beam is much more divergent than it will be later when the current is sufficient for the pinch effect to confine the beam. The impact of the initially diverged beam on the surrounding surfaces and on the anode liberates gaseous substances which begin to be ionized by the beam. Beam electrons in the range of energy 0.5 to 10.0 mega-electron-volts have an ionization efficiency in most of these gaseous products of the order of magnitude of 0.01 ionization per centimeter of travel per Torr so that wherever the gas pressure has risen to more than three Torr, there will be produced within the first nano-second, one ionization per unit volume everywhere in the beam for every relativistic beam electron per unit volume. Immediately that ionizations are produced, the electric field applied between the electrodes in the diode tries to drive the ionization electrons towards the anode, leaving behind the positive ions. This is opposed by the following. While the relativistic beam current is still increasing in the initial part of the pulse, there are electric fields induced in and around the beam that tend to produce motion of the ionization electrons towards the cathode. These reverse current densities tend to over-lay the injected relativistic beam current densities in such a manner as to mask the magnetic field of the beam. Placing these ionization electrons in motion in this manner also reduces the density of the ionization electrons thereby masking the change in the electric field due to the charge on the electrons in the beam. There is of course some inertial lag in forming the reverse current so that there are some portions of the magnetic and electric fields of the beam which are not masked. The reverse

motion of the ionization electrons in those unmasked fields tends to drive those electrons out of the beam channel.

As soon as the current in the beam has risen to the steady value it has through most of the pulse, the induced reverse acceleration of ionization electrons ceases, and the electric field applied across the diode is able to drive those electrons out of the beam channel and into the anode. Because of the greater mass of the ions, the ions remain in the beam channel through most or all of the pulse.

A 100,000 ampere relativistic electron beam concentrated to a 0.1 millimeter radius has a density of $6.6 \cdot 10^{16}$ or about the same as a gas at room temperature and a pressure of two Torr. Hence, a gas density the same as that of the same gas at a pressure of two Torr and at room temperature would be adequate to provide enough ions to fully neutralize the space charge while concentrating the beam to a radius of the order of 0.1 millimeter, provided all of the ionization electrons have been removed from the beam channel. The extent to which the ionization electrons have not been removed from the beam channel due to the inertial lag of ejection behind the ejecting forces, determines the amount of additional ionizable gas which must be provided in the beam channel.

In addition to the above processes, the collisions of the beam electrons with the ionization electrons also tend to drive the ionization electrons out of the beam channel. This can occur either before or after an ionization has taken place. This continues after full neutralization of the space charge of the relativistic beam has taken place and results in overneutralization of the space charge with a resulting further electric pinching of the beam in addition to the magnetic pinching of the beam.

Experiments

Experiments are being continued in order to find the most effective ways for introducing and ionizing gases in the beam channel for the purpose of producing the super-pinch. Measurements are being made on the beam channel and target region using several kinds of observations as follows.

The damage patterns in various forms of metallic and graphite targets have been observed to determine the diameter of the impact area and the effects of the penetration and scattering of the very high energy beam electrons in the target. These observations have confirmed the calculations of Dr. Dale Henderson of the Los Alamos Scientific Laboratory which predict that the mean depth at which the energy of the beam is deposited in the target is much less than the "range" of the electrons (order of magnitude of one-sixth of the "range") because the high energy beam electrons are scattered in direction before most of this energy is deposited and the rest of the energy is deposited with little additional penetration. For example, the impact of a 3 to 4 megavolt beam on an aluminum target 3 millimeters thick results in most of the energy being deposited within the middle one millimeter raising this material to so high a temperature that the front and back one millimeter thicknesses are blasted away, leaving a clean hole and exposing the edge of the middle one millimeter in the remaining target material to examination and showing evidence of the high temperature generated there.

A calorimeter located behind a small diameter aperture is used for measuring the portion of the beam that has been focused to within that diameter. Simultaneous measurements of the time-dependence of the current to the calorimeter and the time-dependence of the voltage on the cathode show that reverse currents induced during the initial rising current in the pulse do not seriously falsify these measurements early in the pulse but the currents induced during the termination of the pulse can be misleading unless it is recognized that the total current to the calorimeter consists both of the beam current and also a rather slowly decreasing induced current.

Several methods are being used for measuring the diameter to which the beam has been concentrated. In one of these, the neutron yield from the so-called "fusion" reactions from deuterium-containing targets is measured, and from these yields, the temperature to which the target has been raised can be

determined. From this temperature, the yield of X-rays can be predicted. In these measurements, scintillation detectors with photo-multipliers are used both forward and laterally. The effect of X-rays is gated out and the time-of-flight signal corresponding to thermally produced neutrons is used for identifying those neutrons and determining the temperature attained in the target.

In some more recent experiments, we have successfully projected the beam out of the diode through a 0.05 millimeter titanium foil into room air at atmospheric pressure while holding the beam to the same or smaller radius. The focused beam struck metal targets 50 millimeters away and blasted holes through them. This was done by providing for the return current with six 1.5 millimeter aluminum rods arranged as a 10 millimeter diameter squirrel cage with a 3 millimeter thick aluminum disk as target at 50 millimeters from the foil. Further pinching of the beam in the course of its travel towards the target after emergence through the titanium foil has been observed. Now that the beam has been successfully brought out of the machine into the room, a Kerr cell is to be combined with a telephoto lens in a camera to separate the after-pulse effects from the processes during the pulse. This will permit projecting the pulsed beam through a thin plastic foil at grazing incidence and directly photographing the impact pattern through appropriate filters.

Ion Acceleration

Following upon some early pioneering work performed in Russia in 1961, investigators using relativistic electron beams at not only our Laboratory but also at a number of others have observed that these electron beams can accelerate positive ions and deliver them to the anode with energies much greater than that corresponding to the voltage applied to the diode. In one instance, ion energies at impact as high as 25 mega-electron-volts have been observed when only 4 mega-volts was applied to the diode. Delivery of the ions to the anode requires that there be an accelerating mechanism at work which is much more powerful than the direct effect of the electric field in the diode acting on the positive ions because not only are the energies much greater than that which the voltage across the diode could produce but also the fact that the positive ions are delivered to the anode requires that the powerful mechanism is working in the opposite direction to that of the voltage across the tube. However, the total number of ions accelerated in this way is small and only a very small part of the energy used in the discharge appears as ion energy delivered at the anode in this way. The accelerating mechanism is an inefficient and uncontrolled one which seems to depend upon some kind of modulation or bunching of the electron beam so as to provide potential troughs in which positive ions originating near the cathode can become trapped and carried along with the beam. A possible alternative explanation might be that there are local transient super-pinches which accelerate the ions. The locally rapidly changing current density in the beam induces electric fields which accelerate positive ions in the direction opposite to that of the electric field applied to the diode.

Coherent Acceleration

The above kind of ion acceleration should not be confused with the coherent acceleration of ion clusters which this Laboratory has been studying, and with which we expect to be able not only to deliver ions with more than 100,000 times the energy, but also to do so with ion cluster consisting of 10^{10} ions per cluster. In order to do this, we must be able to produce super-pinched relativistic beams and control them as envisioned in the objective of this program.

Experiments have been continued in which the focused beam is brought out into the room air. The high energy electrons scattered throughout the experimental space are found to be too penetrative and destructive to our more sensitive diagnostic equipments and enclosures have been built which include quartz windows through which visible and ultraviolet radiations can be used in photographing the beam and target region.

In the diode the titanium sheet anode has been covered with a graphite shroud, 12.5 mm thick and through which there was a 6 mm hole through which the beam reliably focuses enough to pass through the titanium sheet. Experiments are proceeding with the use of small pellets of polyethylene located on the center of the titanium sheet or with small amounts of polyethylene around the wall of the hole to serve as a source of plasma material with which to produce super-pinching of the beam in the diode.

Experiments have been continued in which the electron beam from the dielectric cathode passes through small amounts of polyethylene or other plastic materials in the form of very thin mats, knitted meshes, or two or more single fibers criss-crossed on axis in front of the cathode. When these materials are located approximately 10 mm from the tip of the cathode, it is found that the acceleration of protons towards graphite shrouds or anodes located approximately 50 mm further downstream produce radioactivity which is somewhat spread out over the anode area. This indicates that the acceleration of ions is not a reliable method for delivery of positive ions into the beam channel for the purpose of producing the super-pinching of the beam, but that acceleration of ion bunches does occur during a part of the pulse.

Using an image converter camera which is recording only during the principle pulse in order to avoid recording the much more intensely illuminated

flying debris following the pulse, it has been observed that the discharge on the dielectric cathode follows somewhat jagged streaks except near the tip of the cathode where the dielectric has been tapered down to approximately 1 mm diameter. There is also an indication that the tip of the cathode becomes surrounded by a diffusely illuminated plume during the latter part of the pulse.

A new technique to study the speed of surface breakdown along the length of a dielectric guide cathode is being prepared. The onset of light output from the high voltage breakdown is observed simultaneously at two locations along the guide through fiber optic light pipes connected to fast photomultipliers. By measuring the relative delay between the onset of light nearest the cathode with that farther downstream on the guide surface, the speed of breakdown of the guide can be measured. Nanosecond timing accuracy can be achieved using a time to pulse height converter triggered with signals from the photomultipliers that have been processed through constant position timing discriminators. These discriminators provide accurate timing of events despite wide variation in pulse height and the slow rise time of the discharge light relative to the time interval to be measured. Factors affecting the breakdown such as guide surface texture, composition, shape, and length are to be examined.

A graduate student in Chemical Engineering has been interested in doing his thesis on the development of production methods for deuterated polyethylene either in the form of long single chains or in shorter forked chains. A choice is to be made on the basis of which forms are best suited to the needs of this investigation. Extensive safety precautions are being used in this work because of the explosive nature of the materials and processes involved.

The equipments which are generally used in relativistic electron beam research have incorporated discharge tubes which are cylindrical in form along the axis of which a metallic post is used for holding the cathode. The behavior of such a configuration is essentially that of a coaxial cable with a resistive load at one end extending from the tip of the cathode to a flat plate serving as the anode. Experiments have been initiated in which the discharge tube consists of a converging cone along the axis of which the cathode supporting post is also tapered in such a way that the ratio of the radii of the post and the outer wall remains constant. With this arrangement the impedance of the

line per unit length remains constant while at the same time the azimuthal magnetic field around the post and cathode increases at the same rate as does the radial electric field. Various configurations are to be tried surrounding the cathode-anode gap while taking advantage of the greatly reduced dimensions for the purpose of introducing ion flows into the beam channel for producing the super-pinch.

The electron beams brought through the titanium sheet are to be projected on 30 mil and 60 mil polyethylene sheets at nearly grazing incidence in order to get both image converter photographs of the impact pattern of the beam on the sheet and also to be able to measure the spectra of the material to determine the temperatures obtained. Metallic sheets are not useful for this purpose because the induced currents in the metallic sheets magnetically repel the approaching electron beam and prevent impact.

As soon as the spectroscopic studies of the inclined target sheets have been completed, it should be possible to select one or a few spectral lines at the various locations with which to observe the time dependence of the rise in temperature of the target material.

Speed of Breakdown

A technique to measure the speed of formation of the breakdown streams which form along the length of the dielectric rod cathodes is being developed. This study was spurred by experiments performed in May 1975, which, using time integrated 35 mm photographs as well as 10 nanosecond exposure image converter photographs taken during the beam time, indicated the existence of bright submillimeter streamers along the surface of the dielectric rod during the beam. By measuring the time difference between the advent of the earliest light emitted upstream along the rod, near the metal rod holder, and the earliest light at another location farther downstream, the speed of the rod's breakdown can be inferred.

The technique employs a lens which forms an image of the dielectric rod. The ends of two fiber optic light pipes, situated at upstream and downstream locations along the image, feed the streamer light to separate photomultiplier tubes. These luminosity waveforms are each fed into Ortec 473 discriminators which produce timing pulses corresponding in time to the leading edges of the photomultiplier signals. The discriminator outputs are fed into an Ortec 457 Biased Time to Amplitude Converter (TAC), where the time interval between the signals is measured. In the TAC circuitry, the upstream discriminator signal initiates a voltage ramp which is designed to rise linearly in time from zero to ten volts over a selected time interval, such as ten nanoseconds. The other discriminator's output, corresponding to the start of the light downstream, stops the ramp at some value along its rise. The ramp's final amplitude corresponds to the time difference between the upstream and downstream signals. This time difference is due to several factors. All but one of these can be classed as differences in the transit time within the two photomultipliers, cable length differences, and the differences in the processing times within the discriminators and the TAC. These are all constant from shot to shot. The other source of a time difference is the time interval between light first being produced on the rod near the metal cathode holder and light beginning downstream. This latter interval should be zero if the two channels are observing the same location on the rod. By noting the voltage attained by the ramp when both the upstream and downstream circuits are observing the same location (simultaneously occurring light) and then comparing

this to the ramp's amplitude when the downstream circuit observes light several centimeters farther down the rod from the upstream circuit, a time difference between the two cases can be measured. A value for the velocity of breakdown can then be determined from the known separation of the fiber optics.

Waveforms

An in situ calibration measurement of the Boeing magnetic loop current probe was made at low current levels (55 A peak). A 1.25 inch diameter stainless steel shaft was placed along the axis of the Boeing coaxial diode tube. At the input end of the tube, a calibrated voltage pulse, risetime = 16 ns and pulsewidth = 100 ns, was applied to the inner shaft. This pulse travelled down the guide structure past the magnetic loop position and was terminated into a 50 ohm load resistance, matching the pulse generator source impedance. A Tektronix CT-2 current transformer measured the input shaft current at the ground side of the 50 ohm termination resistor to be 55 A peak. The magnetic loop probe output voltage was measured to be 0.145 volt peak, implying a calibration factor of 2.64 volts/kA (or 68.2 kA/div for the 519 osc. with 20 x attenuation).

Similarly, the Boeing capacitive voltage divider monitor was calibrated at low voltage levels (4.25 kV peak). For a peak input voltage of about 4.25 kV, an output voltage from the capacitive voltage monitor was measured to be 0.400 volt peak, implying a calibration factor of 94.1 volts/MV (or $\frac{1.91 \text{ M volts}}{\text{div}}$ for the Type 510 oscilloscope with 20 x attenuation).

Termination of Program

During the past year the Board of Governors of the Consolidated Universities of North Carolina has passed a new regulation requiring that no person on the faculty at any of these universities will be permitted to continue even on a part-time basis as a regular member of the faculty beyond the age of 72. For that reason this grant has had to be terminated not later than June 30, 1976, and the chief investigator has had to make other arrangements in order to be able to continue with this work. The only procedure available has been to terminate this project and initiate a new project under the leadership of a different chief investigator, namely Professor Wesley O. Doggett, which has been done under AFOSR grant number F49620-76-C-0007 with the present chief investigator functioning as a consultant under that new grant for a limited period of time and at a severely reduction rate of support.

The tasks which are to be undertaken in this work will include:

(1) to greatly revise and improve the methods for measuring voltage and current in the beam of electrons delivered to the target;

(2) final refinements of methods for measuring the speed of breakdown in discharges over the dielectric cathodes and determination as well as possible the breakdown mechanisms; and

(3) ascertaining as well as possible in the limited time available the processes in a tapered diode.

PUBLICATIONS

1. Roberts, T. G. and W. H. Bennett, "Intense Pinched Beam of Relativistic Electrons," Bull. Amer. Phys. Soc., 11, 523 (1966).

2. Roberts, T. G. and W. H. Bennett, "Experiments with Intense Pulsed Beams at Relativistic Energies," Bull. Amer. Phys. Soc., 12, 481 (1967).

3. Bennett, W. H. and T. G. Roberts, "Theory of Intense Pulsed Beams at Relativistic Energies," Bull. Amer. Phys. Soc., 12, 481 (1967).

4. Cox, James L., Jr. and W. H. Bennett, "Induced Reversed Current Produced by Injection of a Relativistic Pulse into a Linear Pinch," Bull. Amer. Phys. Soc., 12, 481 (1967).

5. Roberts, T. G. and W. H. Bennett, "The Pinch Effect in Pulsed Streams at Relativistic Energies," Plasma Physics, 10, 381-389 (1968).

6. Roberts, T. G. and W. H. Bennett, "The Propagation of Intense Pulsed Beams at Relativistic Energies in Plasma Columns," Bull. Amer. Phys. Soc., 13, 244 (1968).

7. Cox, J. L., Jr. and W. H. Bennett, "Reverse Current Induced by Injection of a Relativistic Electron Beam into a Pinched Plasma," Bull. Amer. Phys. Soc., 13, 599 (1968).

8. Roberts, T. G. and W. H. Bennett, "Stabilization of a Curved Guiding Plasma for Relativistic Electron Beams," Bull. Amer. Phys. Soc., 13, 1709 (1968).

9. Roberts, T. G. and W. H. Bennett, "Relativistic Beam Focusing," Bull. Amer. Phys. Soc., 14, 581 (1969).

10. Roberts, T. G. and W. H. Bennett, "On the Maximum Current Which Undriven Relativistic Beams May Possess," Bull. Amer. Phys. Soc. for SESAPS, (Nov. 1969).

11. Doggett, W. O. and W. H. Bennett, "Basis for Coherent Acceleration of Ion Clusters by Electron Beams," Bull. Amer. Phys. Soc., 14, 1048 (1969).

12. Cox, J. L., Jr. and W. H. Bennett, "The Reverse Current Induced by Injection of a Relativistic Electron Beam into a Pinched Plasma," Physics of Fluids (Jan. 1970).

13. Doggett, W. O. and W. H. Bennett, "Dependence of Coherent Acceleration of Ion Bunches on Electron Stream Parameters," Wash. Mtg. of the Amer. Phys. Soc. (Apr. 1970).

14. Doggett, W. O., David L. Morrow, Daniel Phillips, Ray Stringfield, Jr., and W. H. Bennett, "Luminosity Studies of a Z-Pinch," Wash. Mtg. of Amer. Phys. Soc. (Nov. 1970).

PUBLICATIONS, Continued

15. Doggett, W. O., "Coherent Acceleration of Ions with Relativistic Electron Beams," Bull. Amer. Phys. Soc., 15, 1347 (Nov. 1970).

16. Phillips, J. Daniel, David L. Morrow, Ray M. Stringfield, Jr., W. O. Doggett, and W. H. Bennett, "Structure of Linear Pinch with Six Wires as Return Circuit," Bull. Amer. Phys. Soc., 16, 595 (Apr. 1971).

17. Phillips, J. Daniel, David L. Morrow, Ray M. Stringfield, Jr., W. O. Doggett, and W. H. Bennett, "A Low Pressure Pinch in Argon," Bull. Amer. Phys. Soc., 16, 595 (Apr. 1971).

18. Bennett, W. H., "Production, Control and Utilization of Extremely High Density Relativistic Streams," Progress Report prepared for 14th Meeting of AFOSR Contractors and Grantees in Physical Energetics, Lubbock, Texas, 1-3 June 1971.

19. Morrow, David L., J. Daniel Phillips, Ray M. Stringfield, Jr., W. O. Doggett, and W. H. Bennett, "Concentration and Guidance of Intense Relativistic Electron Beams," Applied Phys. Letters, 19, 10, 441-443 (Nov. 1971).

20. Stringfield, Ray M., Jr., J. Daniel Phillips, David L. Morrow, W. O. Doggett, and W. H. Bennett, "Cooling Relativistic Beams with the Guide Pinch," Bull. Amer. Phys. Soc., 17, 592 (Apr. 1972).

21. Baity, F. Wallace, David L. Morrow, W. O. Doggett, and W. H. Bennett, "Particles Delivered Through Hole in Cathode of Pinch in Argon," Bull. Amer. Phys. Soc., 17, 593 (Apr. 1972).

22. Bennett, W. H., "Production, Control and Utilization of Extremely High Density Relativistic Streams," Progress Report prepared for 15th Meeting of AFOSR Contractors and Grantees in Physical Energetics, Rochester, New York, 7-9 June 1972.

23. Bennett, W. H., "Production of Intensely Concentrated High Current Relativistic Electron Beams," Bull. Amer. Phys. Soc., 17, 669 (Jun. 1972).

24. Phillips, J. Daniel, Ray M. Stringfield, Jr., F. Wallace Baity, David L. Morrow, John A. Pasour, Wesley O. Doggett, and Willard H. Bennett, "Induced Currents in Beam Targets," Bull. Amer. Phys. Soc., 17, 1030 (Nov. 1972).

25. Stringfield, Ray M., Jr., W. O. Doggett, and Willard H. Bennett, "D-D Fusion Neutron Diagnostics With Nanosecond Resolution," Bull. Amer. Phys. Soc., 18 (1973).

26. Gibson, Richard A. and Willard H. Bennett, "Instabilities in Self-Focused Electrn Beams," IEEE Trans. on Plasma Science, PS-2, 174-181 (Sept. 1974).

PUBLICATIONS, Continued

27. Doggett, Wesley O., Ray M. Stringfield, Jr., David L. Morrow, and Willard H. Bennett, "Ion Acceleration in the Diode Region of a Relativistic Electron Beam Machine," Bull. Amer. Phys. Soc., (Apr. 1975).

28. Doggett, Wesley O., David L. Morrow, Ray M. Stringfield, Jr., Stanley P. Converse, Willard H. Bennett, and Pax S. P. Wei, "Ion Acceleration Using Thin Mats, Meshes and Filaments," Bull. Amer. Phys. Soc., 20, 1234 (Oct. 1975).

29. Converse, Stanley P., Wesley O. Doggett, David L. Morrow, Ray M. Stringfield, Jr., Willard H. Bennett, John Adamski, and James R. Beymer, "Image Converter Study of Dielectric Cathode Processes in the Diode Region of a Relativistic Electron Beam Machine," Bull. Amer. Phys. Soc., 20, 1234 (Oct. 1975).

30. Baity, F. Wallace and Willard H. Bennett, "Snowplow Model of the Tapered Z-Pinch," Bull. Amer. Phys. Soc., 20, 1296 (Oct. 1975).

31. Stringfield, Ray M., Jr., Wesley O. Doggett, David L. Morrow, Richard Copeland, Willard H. Bennett, John Adamski, and P. S. P. Wei, "Surface Flashover Studies of Dielectric Rod Cathodes in the Boeing FX-75 REB Machine," Bull. Amer. Phys. Soc., 21, 673 (Apr. 1976).

32. Baity, F. Wallace and Willard H. Bennett, "The Behavior of a Tapered Z-Pinch Discharge for Use in Focusing Intense Relativistic Electron Beams," Bull. Amer. Phys. Soc., 21, 673 (Apr. 1976).